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GUIDE FOR DETERMINATION OF LIGHTNING IMPULSE ELECTRIC STRENGTH OF INSULATING LIQUIDS

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NEW DELHI 110002

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Indian Standard

GUIDE FOR DETERMINATION OF LIGHTNING IMPULSE ELECTRIC STRENGTH OF INSULATING LIQUIDS

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GUIDE FOR DETERMINATION OF LIGHTNING IMPULSE ELECTRIC STRENGTH OF INSULATING LIQUIDS

0. FOREWORD

0.1 This Indian Standard was adopted by the Indian Standards Institution on 30 April 1986, after the draft finalized by the Liquid and Gaseous Dielectrics Sectional Committee had been approved by the Electrotechnical Division Council.

0.2 Insulating liquids used in high voltage electrical equipment are subjected to transient voltage stresses arising from such causes as lightning strokes and high voltage switching surges, as well as being subjected to steady state voltage stresses associated with continuous operation of the apparatus at normal power frequencies. The ability of the insulating liquids to withstand such transient stresses and its determination has become increasingly important in view of the operating voltage having extended to 400 kV and above.

0.3 Whether such surges are unidirectional or oscillatory, the result will always be a transient operation with positive or negative polarity which requires knowledge of the behaviour of the insulating liquid under these conditions. Although, polarity of the voltage wave has little or no effect on the breakdown strength of the oil in uniform fields, polarity does have a marked effect on the breakdown voltage in non-uniform electrical fields. Much more experience is necessary before the results of the impulse breakdown voltage obtained in test cells employing point sphere geometry can be correlated with the performance of liquids in practical insulating systems. However, experience has shown that in this configuration, the chemical composition of the liquid has a fundamental role in determining the negative impulse breakdown properties.

0.4 In insulating liquids, impulse breakdown is a complex phenomenon and requires the initiation and propagation of a pre-breakdown disturbance. Breakdown voltage appears to be determined by factors such as the voltage wave shape, duration of the applied voltage and the field configuration. To obtain comparable results, all these factors must be clearly defined and kept under control. Even so, a spread of results in frequently observed which is believed to be associated with the random nature of the pre-breakdown mechanisms.

0.5 The transient voltages referred to above, may also vary over a wide range, both in time to reach crest value and time to decay to half crest value or to reach a zero magnitude. The impulse breakdown voltage depends on wave front duration. However, for the purpose of standardization, the methods described here specify only the standard full impulse wave (1·2/50).

0.6 Unlike the power frequency breakdown voltage, the point sphere impulse breakdown is largely independent of such contaminants as moisture and particles. Accordingly, no specific provisions are made to control these contaminants provided their concentrations in the liquid do not exceed the limits for satisfactory serviceability.

0.7 This guide would enable data to be generated on insulating oils of the types of composition being produced in this country and later with suitable modifications, it would be accorded the status of a full test method with specific values for recommendations to be included in the standard covering the insulating liquids.

0.8 In the preparation of this guide considerable assistance has been derived from IEC Doc : 10A (Central Office) 64 'Methods for the determination of the lightning impulse electric strength of insulating liquids', issued by the International Electrotechnical Commission (IEC).

0.9 For the purpose of deciding whether a particular requirement of this standard is complied with, the final value, observed or calculated, expressing the result of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

1. SCOPE

1.1 This guide describes test methods for assessing the electric strength of insulating liquids when subjected to standard lightning impulse in a divergent field.

1.1.1 Two methods are suggested:

a) Method A is based on a step-by-step procedure to provide an estimate of the impulse breakdown voltage under specified conditions; and

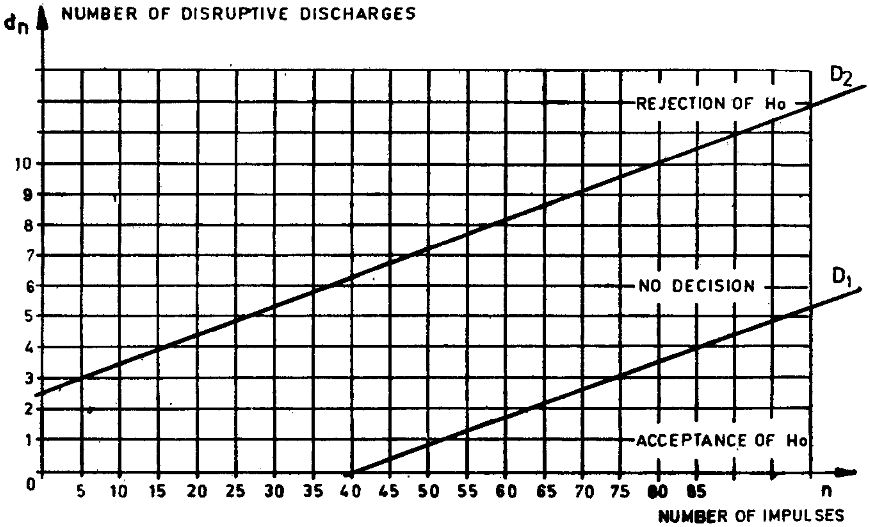
---

*Rules for rounding off numerical values (*revised*).

b) Method B is a statistically designed test to check statistical hypothesis about the impulse breakdown probability of an insulating liquid at a given voltage level.

1.2 Both methods can be applied to insulating liquids, unused or used, the viscosities of which are lower than 350 mm²/s at 40°C.

1.3 Experience suggests that sometimes when an impulse wave is applied to the test cell at a crest level close to the breakdown voltage, breakdown may not occur when Method A is adopted. Then the sequential test Method B should be carried out. A sequence of impulses of constant crest value are applied till breakdown occurs and the result is plotted on a graph paper (Fig. 1).



$P_0 = 10\%$ $P_1 = 5\%$ $P_2 = 15\%$

$\alpha = 5\%$ $\beta = 1\%$

$s = 0{\cdot}092$ $h_1 = 3{\cdot}76$ $h_2 = 2{\cdot}47$

FIG. 1 RULING GRAPH

2. SIGNIFICANCE

2.1 Method A and Method B are intended primarily to establish standardized procedures for assessing the impulse electric strength of insulating liquids. They may serve to differentiate dielectric liquids between each other and to detect variations in their characteristics due to modifications in the chemical composition as a result of change in the manufacturing process and/or feed stocks.

2.2 These methods can be used with positive or negative impulses. Although, no specific suggestions are made regarding the preparation of the liquid sample, it should generally correspond to that followed as good industrial practice used for preparing oils for ac/dc breakdown tests. However, tests made before and after a specific treatment of the sample may be useful for demonstrating the effect of treatment.

3. APPARATUS

3.1 Impulse Generator — The impulse generator should be capable of producing a standard (1·2/50) full wave, adjustable to positive or negative polarity in accordance with the limits defined in IS : 2071 (Part 2)-1976*; in particular, measurement to ± 3 percent of the crest wave voltage is necessary. The voltage supplied should be 300 kV, *Max*, and it is recommended that this voltage be checked continuously. The energy of the impulse generator at 300 kV output should preferably be less than 1 kJ. If the output energy is between 0·1 kJ and 20 kJ, there should be no major difficulties.

3.2 Presetting of Impulse Voltage — This operation is very important. For this reason, peak of voltage should be predetermined to within 1 percent by a manual control charging apparatus or, preferably by means of an automatically triggered apparatus with regulating accuracy to ± 0·5 percent.

3.3 Impulse Voltage Measurement — This should be carried out as specified in IS : 2071 (Part 3) - 1976† and IS : 8090-1976‡.

It is advisable to use an accurately calibrated resistive voltage divider and a crest voltmeter in preference to an oscilloscope. However, calibration of the measuring system by sphere-gap in accordance with IS : 1876-1961§ is also recommended. The error in measurement of the peak value of the impulse voltage should be determined. It should not exceed 3 percent.

3.4 Test-Cell Design

3.4.1 This consists of a closed vessel containing a vertical gap. The volume of liquid under test should be of the order of 300 ml.

Metal parts should be restricted to electrodes and their supports.

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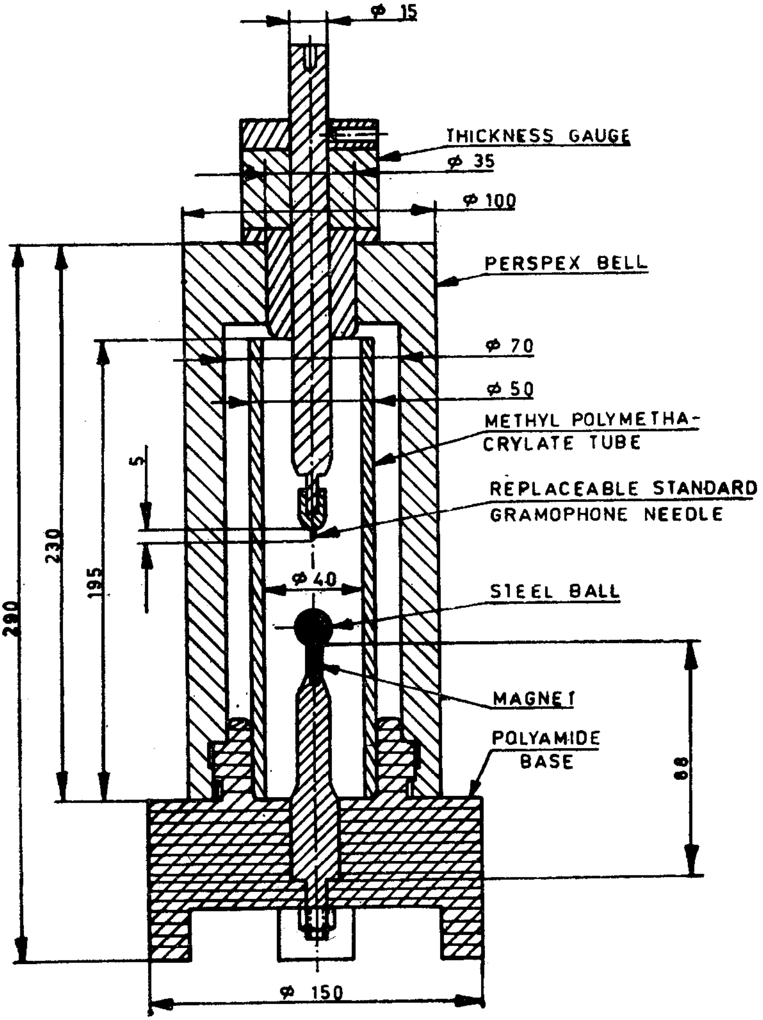
*Methods of high voltage testing: Part 2 Test procedures (*first revision*).

†Methods of high voltage testing: Part 3 Measuring devices (*first revision*).

‡Specification for coupling, branch pipe, nozzle used in hose reel tubing for fire fighting.

§Method for voltage measurement by means of sphere-gaps (one sphere earthed).

3.4.2 The test-cell should be designed for easy dismantling and easy thorough cleaning. Suitable cell is shown in Fig. 2. Dimensions should ensure a possible flashover voltage of over 300 kV.



All dimensions in millimetres.

FIG. 2 NEEDLE-SPHERE ELECTRODE SYSTEM FOR IMPULSE STRENGTH OF OIL

3.4.3 Component insulating materials used in the cell must be of high dielectric strength, thermally stable for temperature up to 80°C, and capable of withstanding insulating liquids, solvents and cleaning agents in conventional use for such liquids.

3.4.4 The gap should be composed of two electrodes forming an adjustable point-to-sphere configuration. Spherical electrodes should be polished steel bearing balls 12·7 mm in diameter. This ball is held in place by a magnet. The point electrode should be a gramophone needle with a conical tip having a radius of curvature of the order of 40 to 70 μm. The shape of the needle and the radius of curvature should be checked by microscope; a check of roughness of the surface is recommended. Appendix A gives a method for measuring the radius of curvature.

4. SAMPLING AND CONDITION OF THE OIL

4.1 Samples of the insulating liquid to be tested shall be taken in accordance with IS : 9434-1979*. The influence of the treatment on the result is of minor significance; the sample should, therefore, be tested as received without drying, filtering or degassing.

5. PREPARATION AND CARE OF CELL

5.1 Electrode Spacing — Set the electrodes gently in contact, checking this with an ohmmeter, and displace one of electrodes by the standard distance 25 mm using a dial micrometer, a helical device or a thickness gauge.

5.2 Prior Cleaning — All parts of the cell, as also the steel balls and gramophone needles, must be de-greased with reagent grade hexane or heptane washed with detergent, rinsed thoroughly in hot tap water followed by distilled water. The parts should then be dried with blasts of oil-free, dehydrated compressed air and kept in a desiccator until required.

5.3 Daily Use — The cell prepared as in **5.2**, is now ready for the tests. The prescribed cleaning must be repeated before testing a different quality of insulating liquid after an appropriate solvent has been used.

6. TEST PREPARATION

6.1 Rinse the test-cell several times with the liquid to be tested. Slowly, fill the test-cell completely making sure that there are no gas bubbles. Allow the liquid to settle for at least five minutes prior to testing.

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*Guide for sampling and analysis of free and dissolved gases and oil from oil-filled electrical equipment.

6.2 The spherical electrode must be grounded; the connection should be as short as possible. The impulse generator output shall be applied to the point electrode and care must be taken to avoid too large a connection loop.

6.3 The temperature of the sample when tested must be in equilibrium with the temperature of the test room; there is no objection to this being between 15 and 30°C. Test-room temperature shall, however, be recorded.

7. TEST PROCEDURE

7.1 Method A—Step-by-Step Method

7.1.1 *Principle* — The initial value of the test voltage, the voltage step and the electrode spacing depend on the breakdown voltage value of the liquid tested.

(1·2/50) standard lightning impulse voltage of a crest value increasing in steps are applied to the liquid specimen using a point-to-sphere electrode system until breakdown occurs. The average of five such values (breakdown voltages) is taken as the lightning impulse electric strength of the liquid under test.

7.1.2 *Procedure*

7.1.2.1 Prepare the test-cell as described in **6**.

7.1.2.2 From Table 1, select appropriate initial value of the test voltage (U_i), voltage step and gap spacing, based on the expected breakdown voltage (U_e) at 15 mm gap spacing.

TABLE 1 SELECTION OF INITIAL VOLTAGE AND GAP

Expected voltage at 15 mm gap [U_e (kV)]	$50 \leqslant U_e \leqslant 100$	$100 < U_e < 250$	$U_e > 250$
Gap (mm)	25·0 ± 0·1	15·0 ± 0·1	10·0 ± 0·1
Initial voltage [U_i (kV)]	$1{\cdot}5\,U_e - 25$	$U_e - 50$	150
Step voltage (kV)	5	5	10

7.1.2.3 Apply an impulse (of selected polarity) at the initial voltage selected and then increase the voltage in steps until breakdown occurs. One impulse shall be applied at each voltage level allowing a minimum of 1 minute to elapse between each successive impulse.

7.1.2.4 The procedure as described above shall be repeated till five breakdown values have been obtained of the liquid tested. After each breakdown, the point electrode must be changed and the sphere electrode rotated. Then follow the procedures noted in **5.1** and **6.1**. The sphere electrode should be changed after every five breakdowns.

7.1.2.5 For the test to be valid, the test sample must have withstood minimum of three levels before breakdown occurs. If breakdown occurs at an earlier time, repeat the test with the lower initial voltage, 5 kV or 10 kV according to the case.

7.1.2.6 Note the crest voltage level at which breakdown occurs as the nominal breakdown voltage.

7.1.2.7 When the breakdown voltage of the particular liquid under test cannot be anticipated determine U_e in accordance with **7.1.2.1** and **7.1.2.3** using a gap of 15 mm, a starting voltage of 50 kV and a voltage step of 10 kV. Then continue as described from **7.1.2.1** to **7.1.2.6**.

If breakdown at 15 mm is not obtained below the flashover voltage of the cell (about 250 kV), reduce the gap spacing to 10 mm or, if necessary to 5 mm.

7.1.3 *Precision* — The precision of a test method is characterized by its repeatability r and its reproducibility R. The value of these quantities for mineral insulating oils only, tested according to method A are given in Table 2.

TABLE 2 REPEATABILITY AND REPRODUCIBILITY OF TEST METHOD A FOR MINERAL TRANSFORMER OIL

POLARITY OF THE IMPULSES	r, PERCENT	R, PERCENT
Negative	7	10
Positive	15	30

NOTE 1 — The value of r and R are expressed as percentage value of the mean breakdown voltage.

NOTE 2 — The values given in the table are determined from results of tests performed on three different mineral insulating oils by seven laboratories.

NOTE 3 — It is suggested that data may be collected on local oils by the laboratories following this test procedure.

NOTE 4 — A 'single result' is the average of five breakdown voltages as given in **7.1.1**.

7.1.3.1 When the method is correctly applied, there is 7 percent probability that the difference between two 'single results' (*see* Notes 3 and 4), obtained from two tests performed on the same oil under the same conditions (same operator, same apparatus, same laboratory and short interval of time), will exceed 7·0 percent of U in case of negative impulses and 15 percent of U in case of positive impulses, U being the average of the two results.

7.1.3.2 When two single results (*see* Note 3 in Table 2) are obtained from tests performed on the same oil but under different conditions (different operators, different apparatus, different laboratories), there is 5 percent probability that the difference between two results will exceed 10 percent of U in case of negative impulses and 30 percent of U in case of positive impulses.

7.1.3.3 If the difference between the two results exceeds the values given in Table 2, further action is required, that is, the apparatus has to be reset and the tests repeated.

7.2 Method B

7.2.1 *Principle* — Experience shows that when an impulse wave is applied to the test-cell at a crest level close to the breakdown voltage measured by Method A, a breakdown may or may not occur. Thus, the notion of breakdown probability, P, which is a function of U but is of unknown value, should be introduced. The sequential test permits the comparison of this breakdown probability with an arbitrary value P_0 and the testing hypothesis H, $H_0 : P \leqslant P_0$, called the null hypothesis against the alternative hypothesis $H_1 : P \geqslant P_0$ (*see* Appendix B).

7.2.1.1 The method consists in applying a sequence of impulses of constant crest value until breakdown occurs, and plotting the results on a graph paper.

The sequential test is carried out until a decision can be made; if no decision is possible, the test will be terminated when a predetermined number of impulses is exceeded.

7.2.2 *Procedure*

7.2.2.1 Mark the axes on the graph paper (Fig. 1) with the values of P_0 and the parameters appropriate as defined in Appendix B.

7.2.2.2 Select a crest value U_0 for the impulse voltage and set the impulse generator (*see* Note 1 under **7.2.2.7**).

7.2.2.3 Prepare the test-cell as laid down in **6** and set the electrode spacing to the desired value.

7.2.2.4 Apply the first impulse of selected polarity and crest value. If there is no breakdown, wait for one minute before applying another impulse and then continue with further impulses until breakdown occurs.

7.2.2.5 Whenever a breakdown occurs, change the point electrode, rotate the sphere electrode, refill the cell, and continue the procedure. The sphere electrode shall be changed after every five breakdowns.

7.2.2.6 Plot each impluse and breakdown on the prepared graph paper (*see* Fig. 1).

7.2.2.7 As long as the plot is within the area limited by the D_1 and D_2 lines (*see* Appendix B), no decision can be taken and the test must be continued (*see* Note 2 below):

If the plot intersects line D_1, the null hypothesis H_0 is accepted : $P \leqslant P_o$.

If the plot intersects line D_2, the null hypothesis H_0 is rejected : $P \geqslant P_o$.

NOTE 1 — Test voltage U_0 may be chosen two voltage steps below the mean breakdown value found by Method A.

NOTE 2 — If after 85 impulses no decision can be made, the test should be repeated at a level 5 or 10 kV lower.

8. REPORT

8.1 The report shall include the following:

a) Reference to Indian Standard Specification;
b) Sample identification;
c) Test-cell configuration;
d) Test identification;
e) Voltage starting level and polarity in case of step test;
f) Selected breakdown probabilities, voltage level and polarity in case of statistical test;
g) Results;
h) Breakdown voltage set, according to the test employed;
j) Ruling graph, according to the test; employed;
k) Test-room temperature;
m) Date of test; and
n) Name of operator.

APPENDIX A

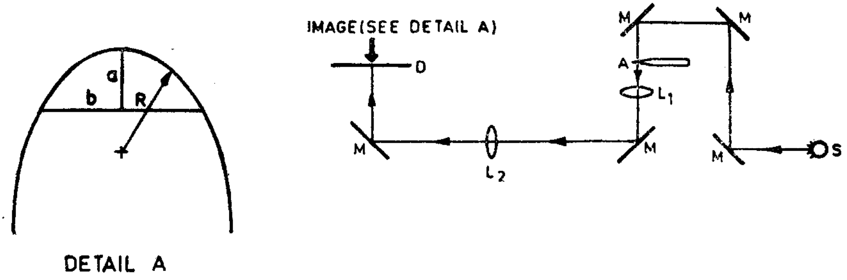
(*Clause* 3.4.4)

MEASUREMENT OF RADIUS OF CURVATURE OF NEEDLES

A-1. As impulse breakdown tests are usually made between a sphere and a point, the radius of curvature of the latter must be measured with the maximum possible accuracy.

A-1.1 The points used are gramophone needles, easily obtainable in the market. Fig. 3 gives the schematic diagram of a system of measuring the radius of curvature with metallographic microscope.

A-1.2 The light from the source of light of the microscope (*S*) is reflected by a set of mirrors at an angle of 45° (*M*) on to the object to be examined (*A*). The image is then projected, through lenses, L_1 and L_2, on to a ground glass plate *D*. Adjust until the object is finally magnified a thousand times.



R	Radius of curvature
a	Sagitta
b	Chord

S	Source of light
M	Mirror
A	Gramophone needle
L_1	Lens, magnification 32 ×
L_2	Lens, magnification 18 ×
D	Ground glass

FIG. 3 MEASUREMENT OF RADIUS OF CURVATURE OF NEEDLES

A-1.3 Using a scale graduated in millimetres, the upright, *a*, corresponding to chord, *b*, should be measured directly on the ground glass plate. For greater accuracy, two measurements corresponding to two chords of different values, *b* and *b′*, should be taken.

The value of the radius of curvature is obtained from the expression:

$$R = \left[\left(\frac{b}{2} \right)^2 + a^2 \right] \Big/ \; 2a$$

The value of *R* is obtained in micrometres when *b* and *a* are expressed in millimetres.

APPENDIX B

(*Clauses* 7.2.1, 7.2.2.1 *and* 7.2.2.7)

SEQUENTIAL TEST FOR COMPARISON OF BREAKDOWN PROBABILITY OF LIQUID DIELECTRICS WITH A STANDARD VALUE — CONSTRUCTION OF A RULING GRAPH

B-1. INTRODUCTION

B-1.1 The principle of sequential test and information regarding the construction of a ruling graph is outlined below.

B-2. LIST OF SYMBOLS

$P(U)$ or P = breakdown probability under standard lightning impulse of a dielectric liquid for a given value of the test voltage U (*see* Note)

P_o = arbitrary fixed breakdown probability which may be related to accepted quality criteria

P_1 = breakdown probability lower than P_o, the value of which is chosen to take into account the test voltage applied

P_2 = breakdown probability higher than P_o and chosen for the same reasons as before

H_o = null hypothesis : $P \leqslant P_o$

H_1 = alternative hypothesis; the hypothesis which is opposed to the null hypothesis, that is, to say $P \geqslant P_o$

α = maximum risk of rejecting H_o when $P \leqslant P_1$

β = maximum risk of accepting H_o when $P \geqslant P_2$

n = number of impulses applied

d_n = number of breakdowns observed after n impulses have been applied

A_n = acceptance number

R_n = rejection number

NOTE — P is unknown in every case and the aim of the sequential test is not to determine this probability which would take considerable time but to compare it with a fixed value P_0 with an accelerated procedure giving information as to satisfactory withstand levels corresponding with good industrial practice.

B-3. A statistical test as a rule permits decision making with accepted error risks from experimental results. It needs the definition of the hypothesis H_o to be tested and the use of a function of the experimental results or measurements given in this case by the points (d_n, n) on the special plots on the prepared graph paper.

In the particular case of the sequential test, the function of the experimental results takes values in three mutually exclusive subsets of the set of experimental results defining, as the test proceeds, the options to be adopted. These are either the acceptance of H_o or the rejection of H_o or the continuation of the test.

B-4. Let P_o be an arbitrary value. We wish to test the hypothesis H_o : $P \leqslant P_o$ against the alternative hypothesis $H_1 : P \geqslant P_o$ at a value U of the voltage applied.

For practical considerations, a value P_1 lower than P_o and an error risk α are fixed such that the probability of rejecting H_o, when $P \leqslant P_1$, is lower than or equal to α.

Likewise a value P_2, higher than P_o, and an error risk β are fixed such that the probability of accepting H_o, when $P \geqslant P_2$, is lower than or equal to β.

B-5. Let L be the likelihood ratio defined as $L = L_2/L_1$, where L_1 is the probability of obtaining a set of observed values with $P = P_1$ and L_2 is the probability of obtaining a set of observed values with $P = P_2$.

The sequential test consists in calculating L at any stage of the experiment and in taking the following decision rules:

If $L \leqslant A$, H_o is accepted;

If $L \geqslant R$, H_o is rejected;

If $A \leqslant L \leqslant R$, the experiment is continued by making an additional observation. A and R are chosen in such a way that the probability of rejecting H_o, when $P = P_1$, is α and the probability of accepting H_o, when $P = P_2$, is β. An approximate calculation shows that:

$A = \beta/(1 - \alpha)$, and

$R = (1 - \beta)/\alpha$

To summarize, if $P \leqslant P_1$ the probability of rejecting H_0 is always lower than or equal to α and if $P \geqslant P_2$ the probability of accepting H_o is always lower than or equal to β.

B-6. The probability, L_1, that d breakdowns would occur in n impulse applications with $P = P_1$ is:

$$L_1 = \frac{(n)}{d} P_1^{d_n} (1 - P_1)^{n-d_n}$$

The probability, L_2, that d breakdowns would occur in n impulse applications with $P = P_2$ is:

$$L_2 = \frac{(n)}{d} P_2^{d_n} (1 - P_2)^{n-d_n};$$

$$L = P_2^d (1 - P_2)^{n-d} \Big/ P_1^d (1 - P_1)^{n-d}$$

Suppose that after n impulses, the condition $L \leqslant A$ is fulfilled; then the expression

$$P_2^d (1 - P_2)^{n-d} \Big/ P_1^d (1 - P_1)^{n-d} \leqslant \beta \Big/ (1-\alpha)$$

yields the following solution for the observed number of discharges d: $d \leqslant h_1 + sn$, where h_1 and s are constants defined by the following expressions:

$$h_1 = \log\frac{\beta}{1-\alpha} \Big/ \left(\log \frac{P_2}{P_1} - \log \frac{1-P_2}{1-P_1} \right)$$

$$s = \log \frac{1-P_2}{1-P_1} \Big/ \left(\log \frac{P_2}{P_1} - \log \frac{1-P_2}{1-P_1} \right)$$

Let

$$A_n = h_1 + s_n \qquad \text{... (1)}$$

When $d \leqslant A_n$, the condition $L \leqslant A$ is fulfilled and the null hypothesis H_o is accepted. Therefore, A_n can be called the acceptance number.

B-7. Suppose now that after n impulses, the condition $L \geqslant R$ is fulfilled.

Proceeding in the same way as before, the following expression is obtained for d : $d \geqslant h_2 + sn$ where s has the same meaning as above and

h_2 is given by:

$$h_2 = \log \frac{1-\beta}{\alpha} \bigg/ \left(\log \frac{P_2}{P_1} - \log \frac{1-P_2}{1-P_1} \right)$$

Let

$$R_n = h_2 + sn \qquad \dots (2)$$

When $d \geqslant R_n$, the condition $L \geqslant R$ is fulfilled and the null hypothesis H_o is rejected. Therefore, R_n can be called the rejection number.

B-8. In the plane of coordinates n and d, the result of the test after n impulses can be represented by the point (n, d_n). A_n and R_n (*see* equations 1 and 2) are the equations of two parallel lines (D_1) and (D_2) respectively which divide the plane in three areas (*see* ruling graph).

If the point (n, d_n) is in the area below the line (D_1), H_o is accepted and if the point is in the area above the line (D_2), H_o is rejected. If the point is between the two lines, no decision is taken and another impulse is applied.

B-9. The ruling graph (Fig. 1) is an example drawn from the following values:

P_o = 10 percent, P_1 = 5 percent, P_2 = 15 percent, α = 5 percent, and

β = 1 percent.

B-10. Unlike the conventional statistical test, the equivalent sequential test does not require a predetermined number of tests to be performed. The number of tests is a random variable, on average lower than the number of tests required by the equivalent conventional statistical test.

Moreover, the probability that the sequential test will be carried on indefinitely is demonstrated to be nil. However, in order to keep the test length within limits, the procedure can be terminated using either a truncating rule or a decision according to **7.2.2**.

INTERNATIONAL SYSTEM OF UNITS (SI UNITS)

Base Units

QUANTITY	UNIT	SYMBOL
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Amount of substance	mole	mol

Supplementary Units

QUANTITY	UNIT	SYMBOL
Plane angle	radian	rad
Solid angle	steradian	sr

Derived Units

QUANTITY	UNIT	SYMBOL	DEFINITION
Force	newton	N	1 N = 1 kg.m/s^2
Energy	joule	J	1 J = 1 N.m
Power	watt	W	1 W = 1 J/s
Flux	weber	Wb	1 Wb = 1 V.s
Flux density	tesla	T	1 T = 1 Wb/m^2
Frequency	hertz	Hz	1 Hz = 1 c/s (s^{-1})
Electric conductance	siemens	S	1 S = 1 A/V
Electromotive force	volt	V	1 V = 1 W/A
Pressure, stress	pascal	Pa	1 Pa = 1 N/m^2